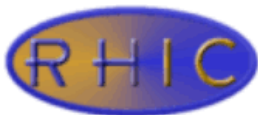


# RHIC R&D - eCooling

Annual DOE/Nuclear Physics Review  
of RHIC Science and Technology

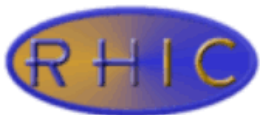
July 24-26, 2006  
Berkner Hall, BNL

Presented on behalf of the many people who contribute  
to the electron cooling R&D effort by  
Ilan Ben-Zvi,  
Collider-Accelerator Department  
Brookhaven National Laboratory

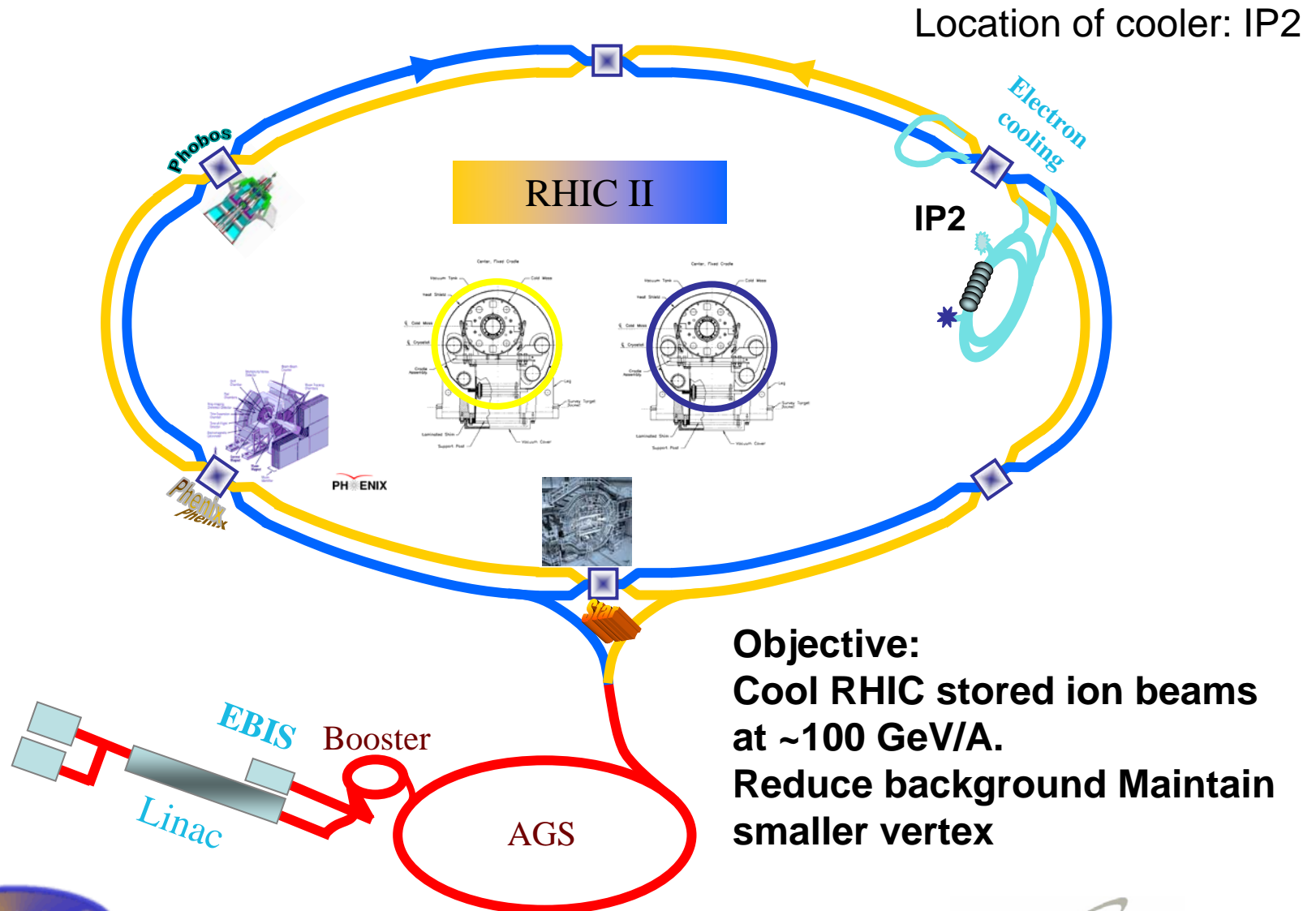


# The RHIC II Upgrade

- Evolution of RHIC to a QCD laboratory calls for a luminosity increase.
- A significant part of the luminosity increase will be through electron cooling.
- Electron cooling is also important for the eRHIC – a high-energy, high-luminosity lepton-hadron collider based on RHIC.
- The energy range (54 MeV electrons) is an order of magnitude increase past the FNAL cooler (4.5 MeV), which is an order of magnitude above all previous coolers (under 0.4 MeV).

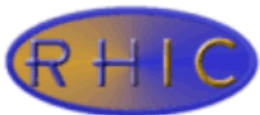


# Schematic Layout of RHIC with an electron cooler at IP2



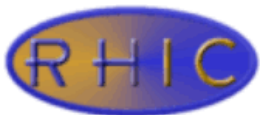
# Many collaborations and multiple support sources

- BNL divisions
  - Instrumentation, Magnet
- National Laboratories
  - Fermilab, JLab, SLAC
- Universities
  - Indiana, Stony Brook, UCLA
- International
  - BINP, JINR, Uppsala, GSI
- Industry
  - AES, Tech-X
- C-AD eCooling group
  - 10 FTE
  - Matrixed support
  - 2 Ph.D.s in last year
  - 3 current students
- Support from
  - BNL Director's Office
  - DOE ONP
  - DOD / ONR
  - DOD / JTO
  - SBIR (various offices)



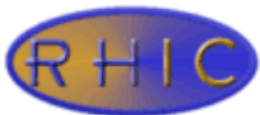
# Major decision made

- Over the past year we decided to change from magnetized electron cooling to classical (non-magnetized) cooling.
- Decision was enabled by improvement in the quality of the electron beam.
- Decision was reviewed by our MAC and a special workshop.
- Gains include reduced electron beam current (4), elimination of magnetization and elimination of very challenging solenoid in cooling section



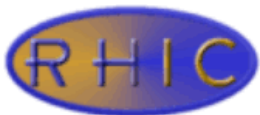
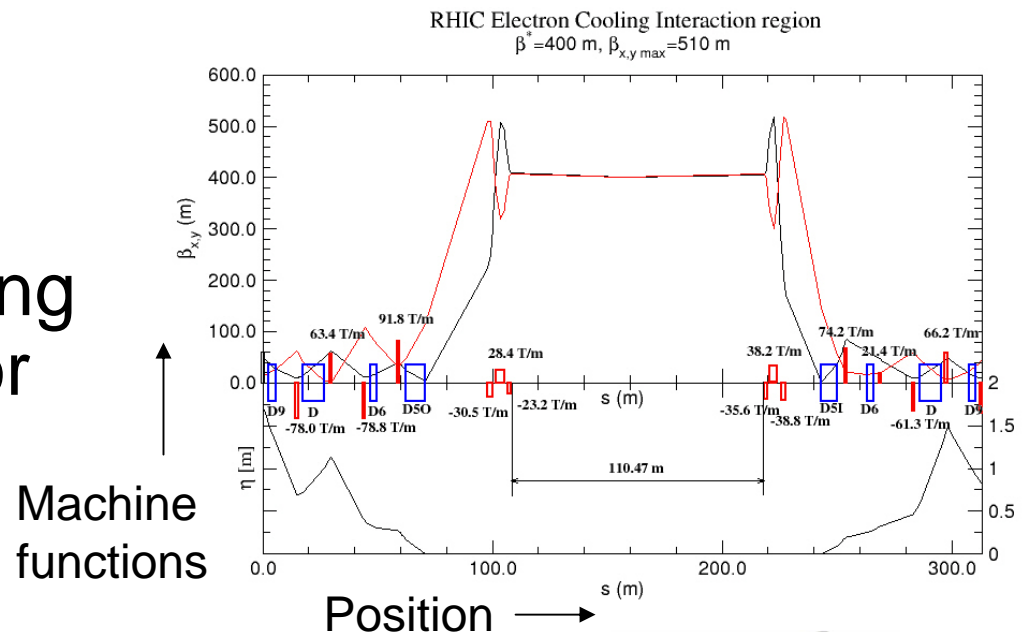
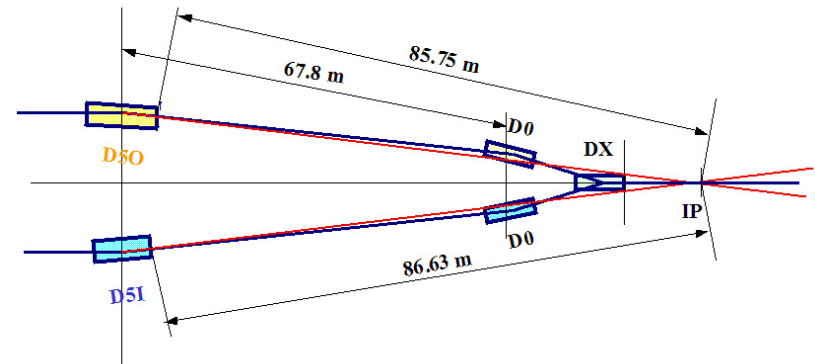
# Proof-of-principle attained

- Proof-of-principle of feasibility of cooling RHIC achieved
  - Theory is within better than a factor of 2 in predicting cooling speed, supported by simulations and experiments
  - Start-to-end simulations of electron beam show that the beam parameters can be achieved.
- Additional R&D on refinements.



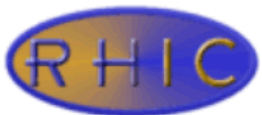
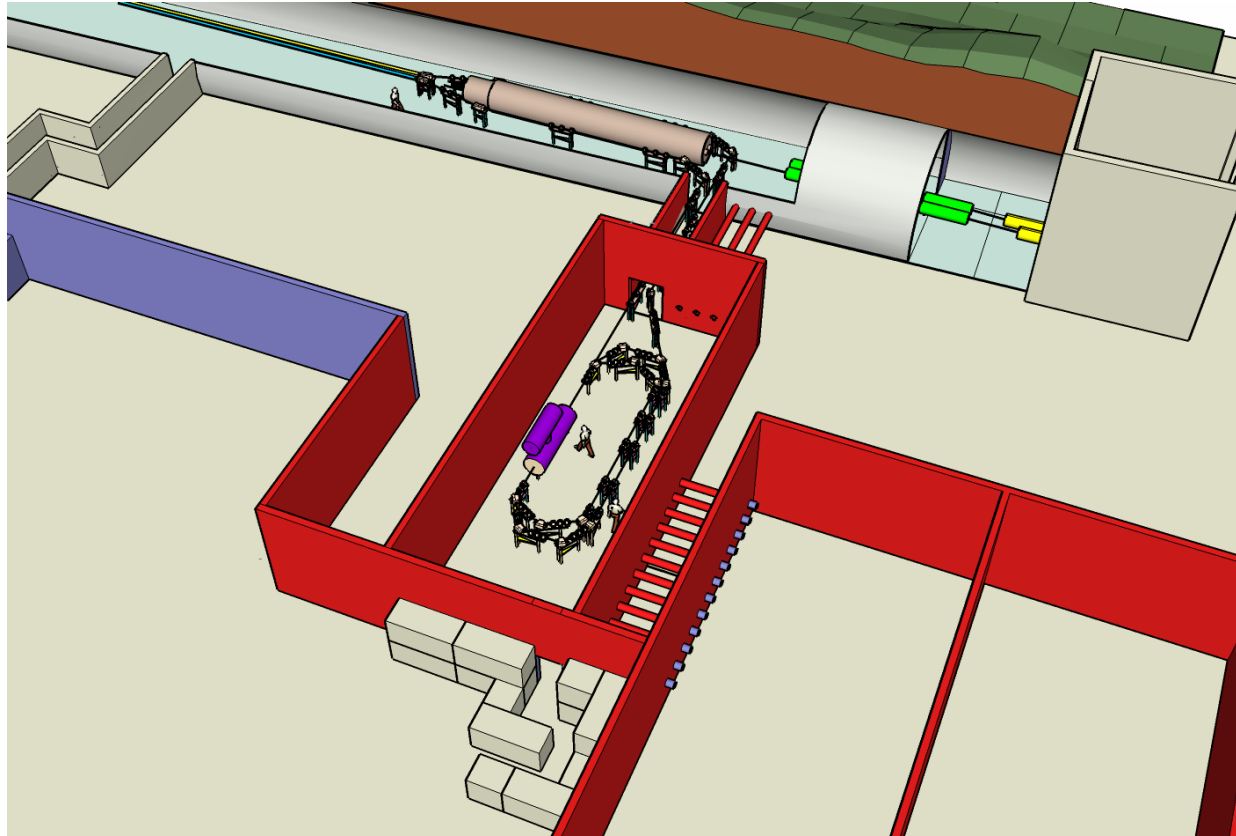
# Modification of the RHIC lattice

- A number of solutions are possible.
- One can accommodate a dispersion free, large  $\beta$  (400 m) long section (110 m) for cooling.

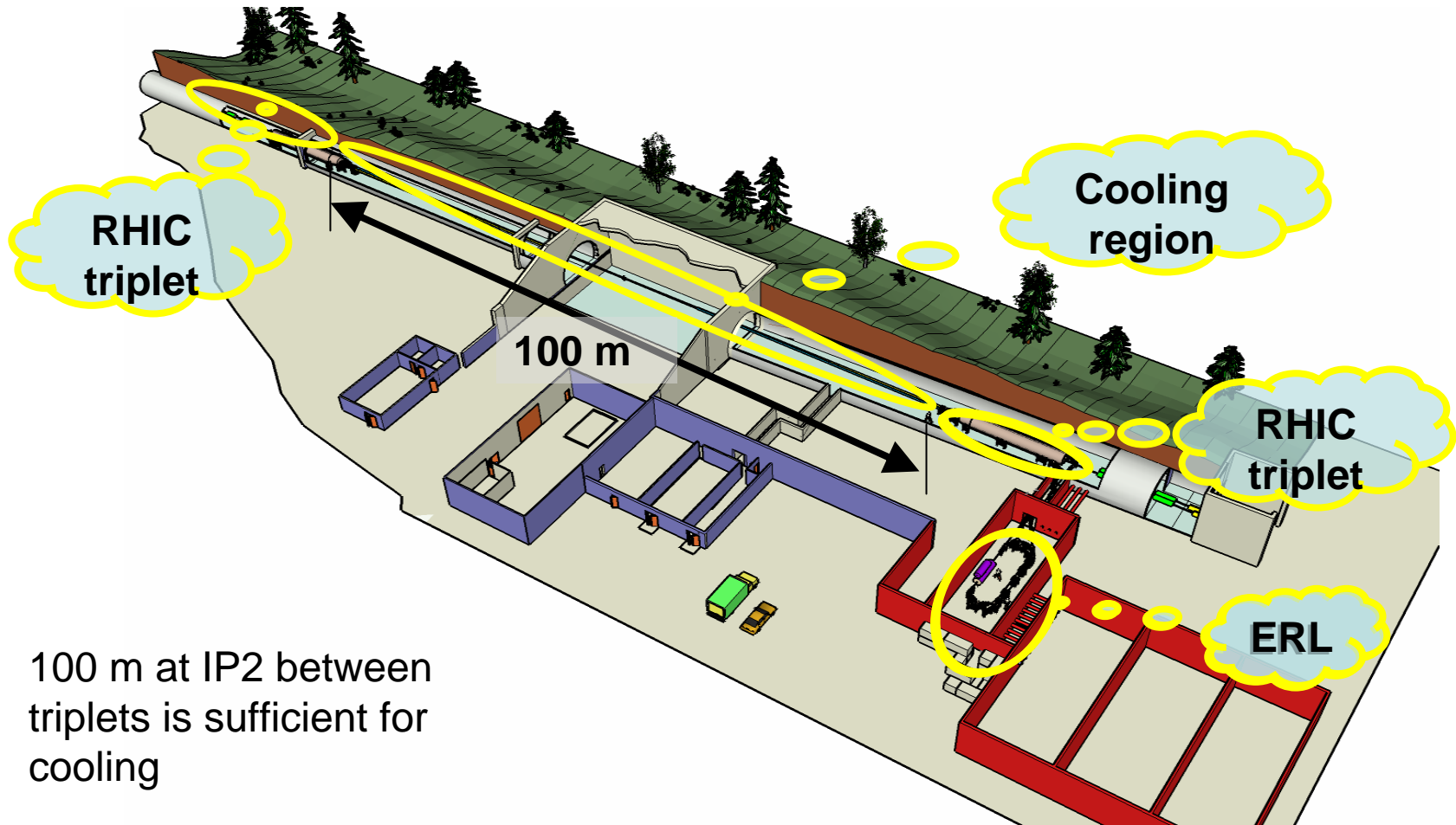


# E-cooler ERL matched to RHIC

Energy of electrons 54 MeV,  
well above DC accelerators  
Need high charge (5 nC)  
and low emittance ( $< 4\mu\text{m}$ )

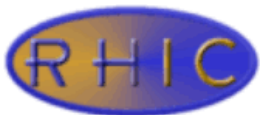


# The RHIC electron cooler at IP2.



# R&D issues

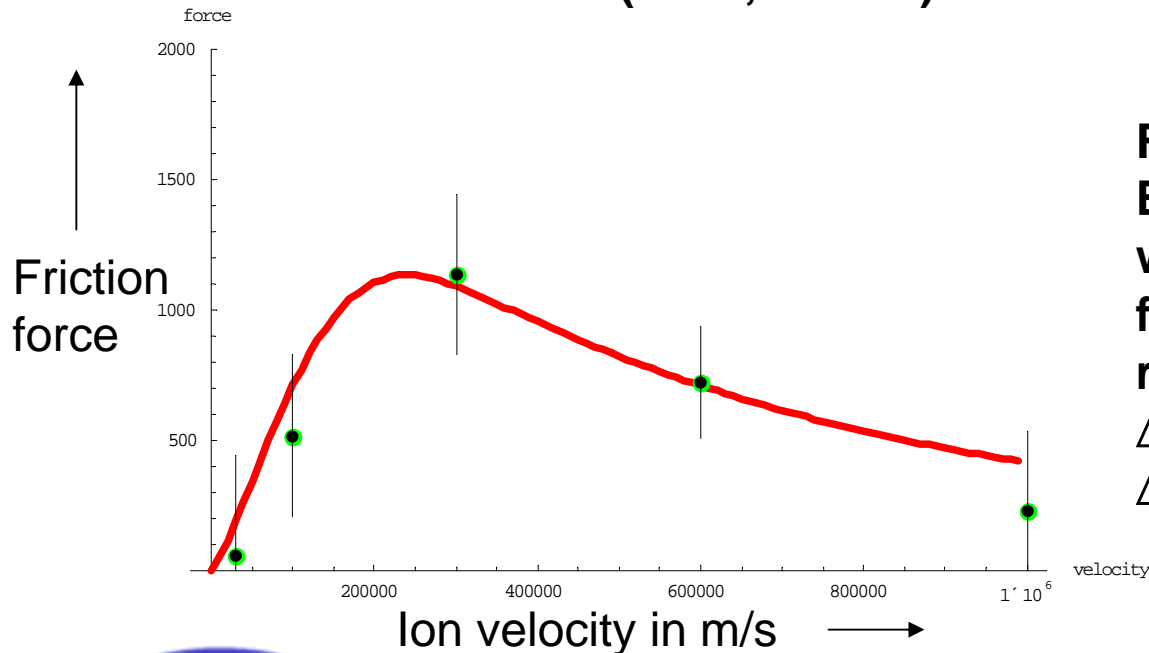
- Understanding the cooling physics in a new regime to reduce uncertainty
  - cooling dynamics simulations with some precision
    - **IBS**, recombination, disintegration
    - benchmarking experiments
    - stability issues
- Developing a high current, energetic, low emittance electron beam
  - Photoinjector (inc. photocathode, laser, etc.) 5 nC, 4 $\mu$ m
  - Energy Recovery Linac, at x10 of state-of-the-art current
    - Preservation of high-charge, low emittance beam
    - Wakes, CSR, space-charge



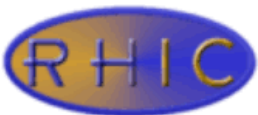
# The cooling “friction” force and dynamics of cooling

$$\vec{F} = -\frac{4\pi m_e e^4 Z^2}{m} \int L \frac{\vec{V}_i - \vec{v}_e}{|\vec{V}_i - \vec{v}_e|^3} f(v_e) d^3 v_e$$

**BETACOOOL (JINR, Dubna) and VORPAL (Tech-X, Colorado)**



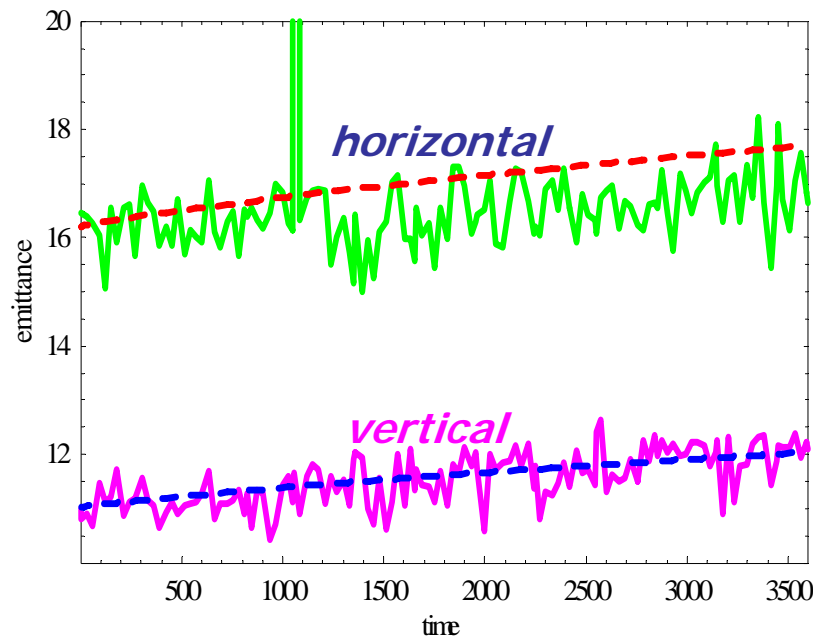
**Formula integration in  
BETACOOOL compared  
with VORPAL simulation from  
first principles.**  
rms electron velocities  
 $\Delta_{||} = 1.0e5$  m/s  
 $\Delta_{\perp} = 4.2e5$  m/s



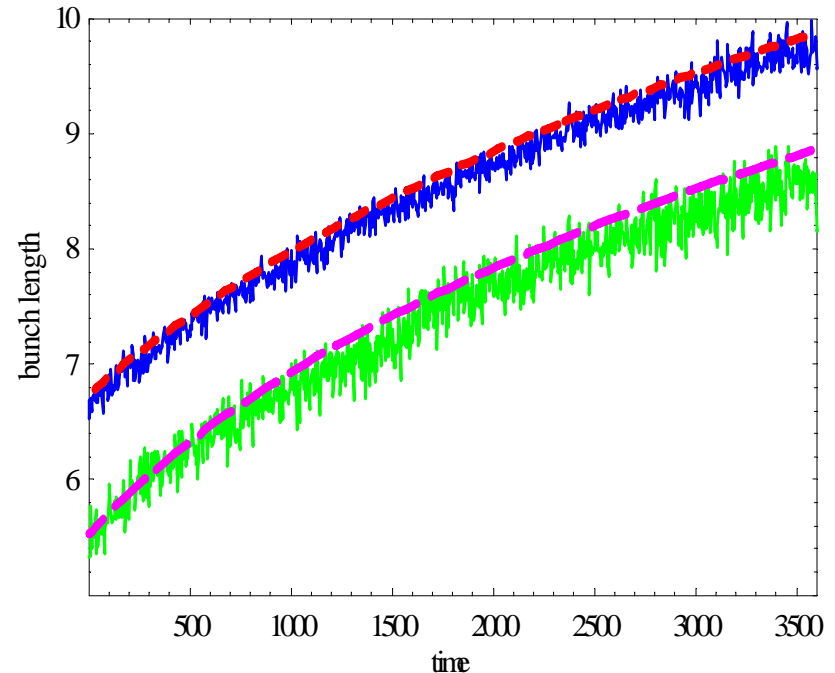
# IBS in RHIC – measurements (noisy curves) vs. theory (smooth curves)

## Example of 2005 data with Cu ions.

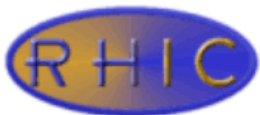
Simulations – Martini's model of IBS for exact designed lattice of RHIC, including derivatives of the lattice functions.



Growth of 95% normalized emittance [ $\mu\text{m}$ ]  
for bunch with intensity  $N=2.9 \cdot 10^9$



FWHM [ns] bunch length growth  
for intensities  $N=2.9 \cdot 10^9$  and  $1.4 \cdot 10^9$

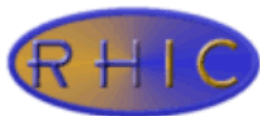


# Experimental benchmarking: using Recycler (FNAL) E-cooling

FNAL uses classical electron cooling (the weak solenoid is used practically only for guiding the electron beam)

FNAL e-cooling allows us to:

1. Benchmark the models for the friction force
2. Study evolution of ion distribution under cooling
3. Study electron cooling together with stochastic cooling

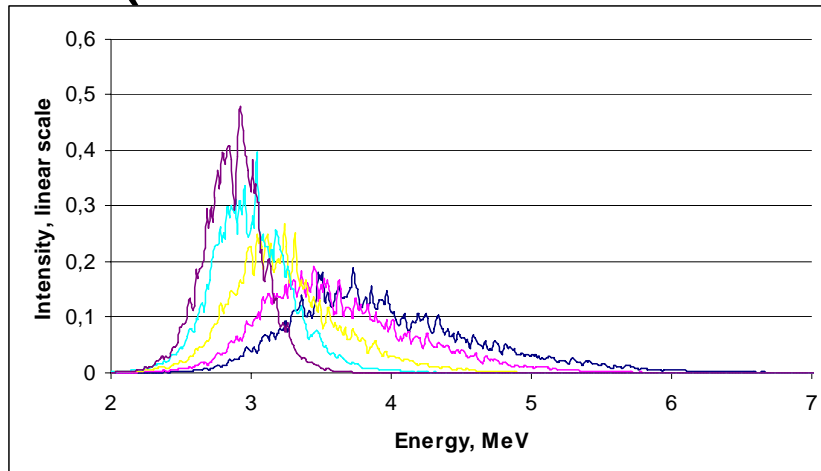


# Benchmarking @ FNAL of evolution (500 mA, 2 keV HV step)

**FNAL**

**Measurement  
10/31/05**

**L. Prost**

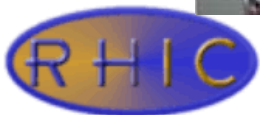
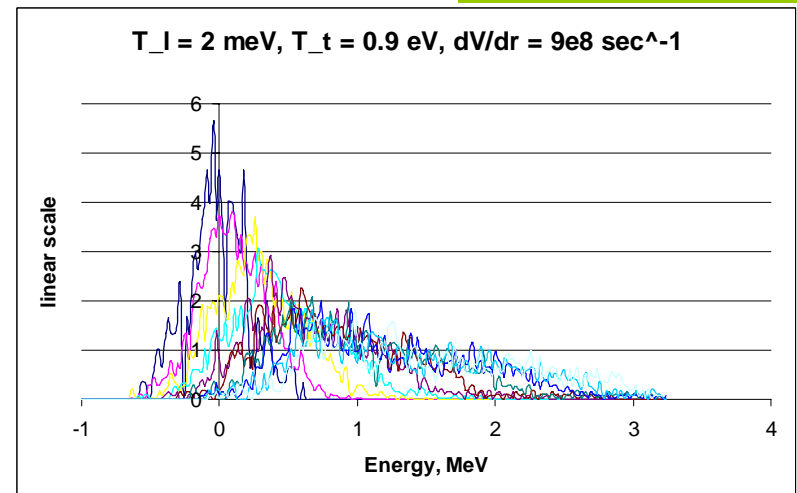


**BETACOOOL**

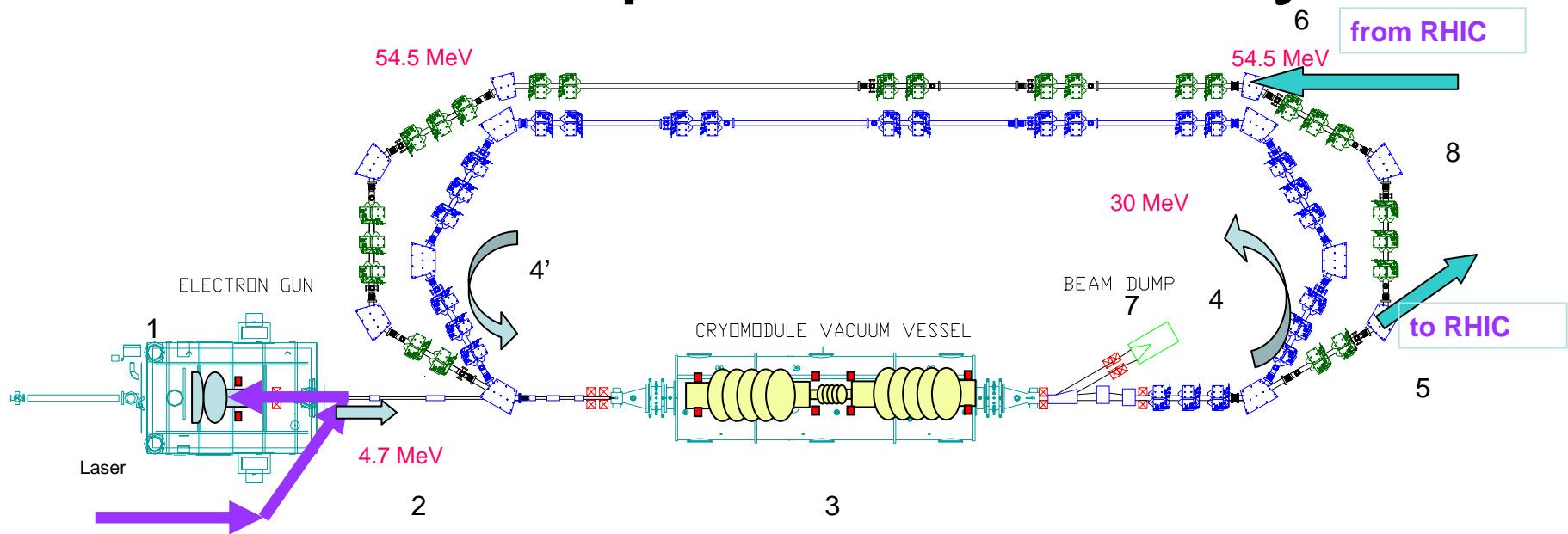
**Simulation**

**12/03/05**

**A. Sidorin**



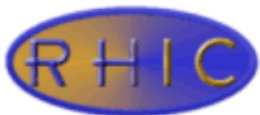
# E-cooler: 2 passes ERL layout



1. SRF Gun,
2. Injection merger line
3. SRF Linac two 5-cell cavities  
and 3<sup>rd</sup> harmonic cavity
- 4, 4'. 180° achromatic turns

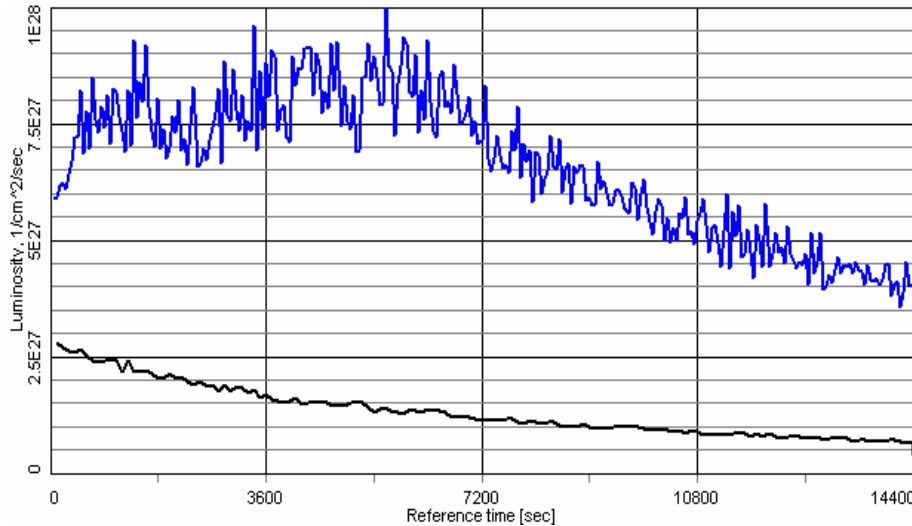
- 5, 6. Transport lines to and from  
RHIC,
7. Ejection line and beam dump
8. Short-cut for independent run of  
the ERL.

54 MeV, 5 nC at 9.4 MHz. RF 703.75 MHz. Gun 5 MeV

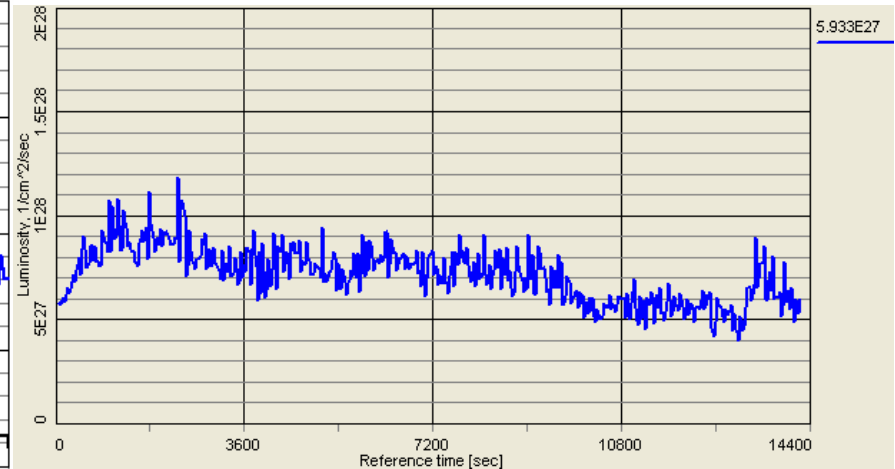


# Au ions ( $N=10^9$ )

## Electrons: 5nC, 4 $\mu\text{m}$ emittance

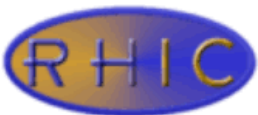


Luminosity with and without cooling  
(modeled beam approach) over  
4 hours

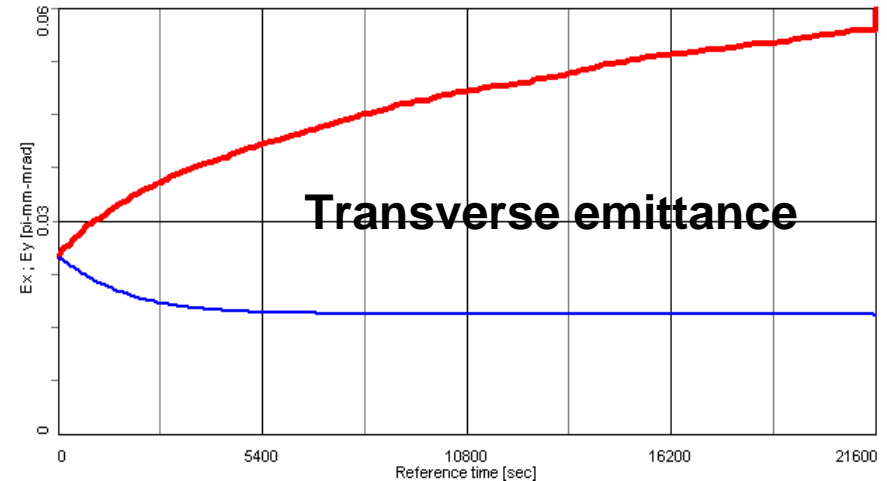
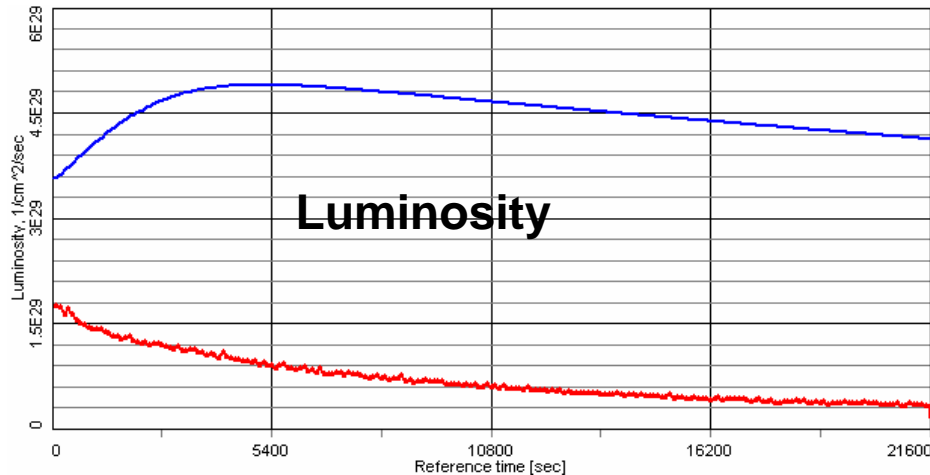


Same as on left, but with (coarse)  
control of cooling rate

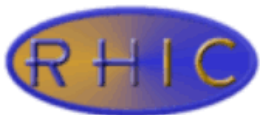
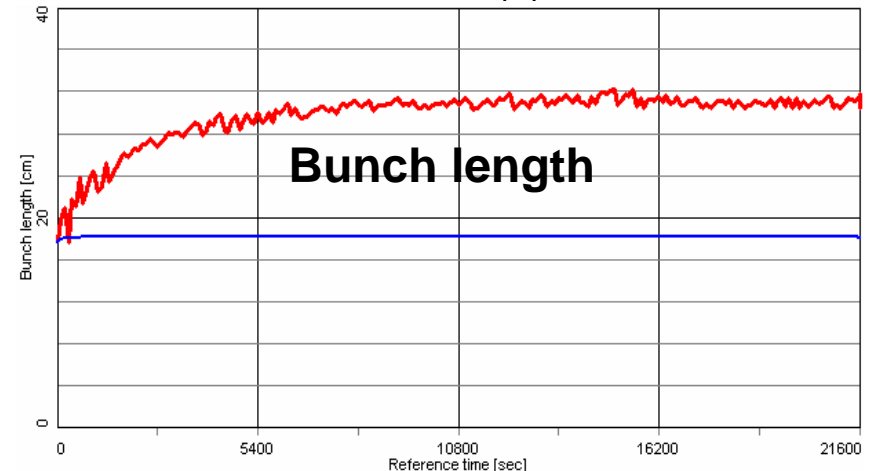
$$\langle L \rangle = 6.9 \times 10^{27}$$



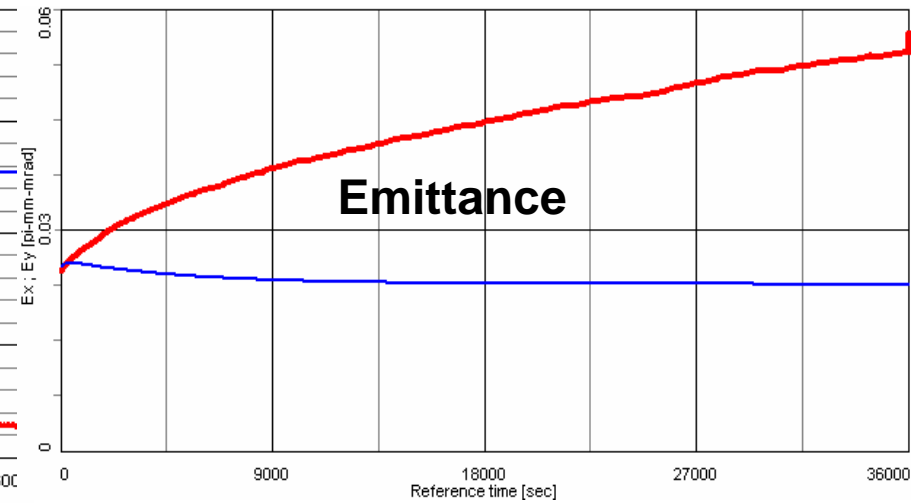
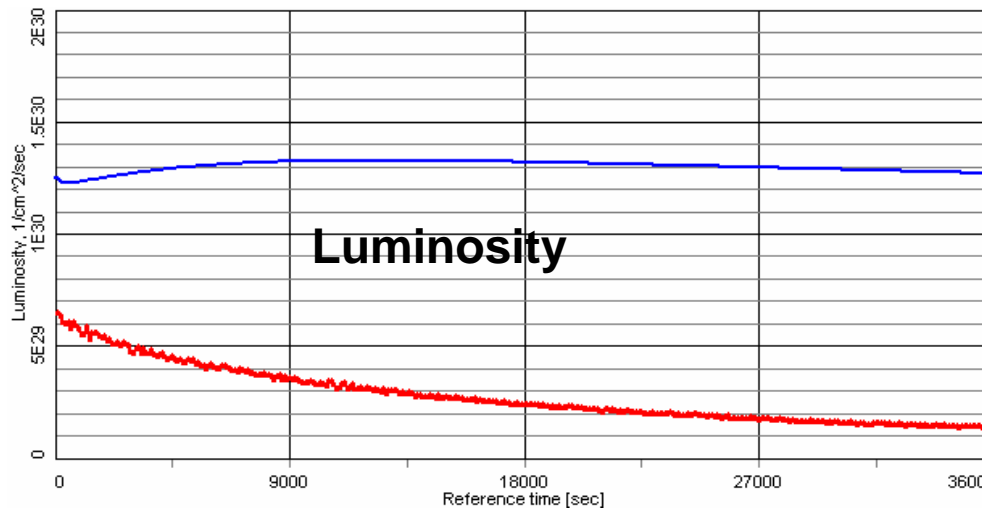
# $N=8 \times 10^9$ Cu ions with (blue) and without (red) cooling



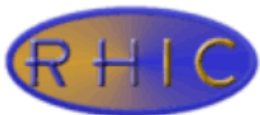
Electron beam 8nC,  
4  $\mu\text{m}$  emittance,  
6 hour store:  
 $\langle L \rangle (\text{cooling}) / \langle L \rangle (\text{without}) = 6.4$



# $1.5 \times 10^{10}$ Si ions – Luminosity with (blue) and without (red) cooling

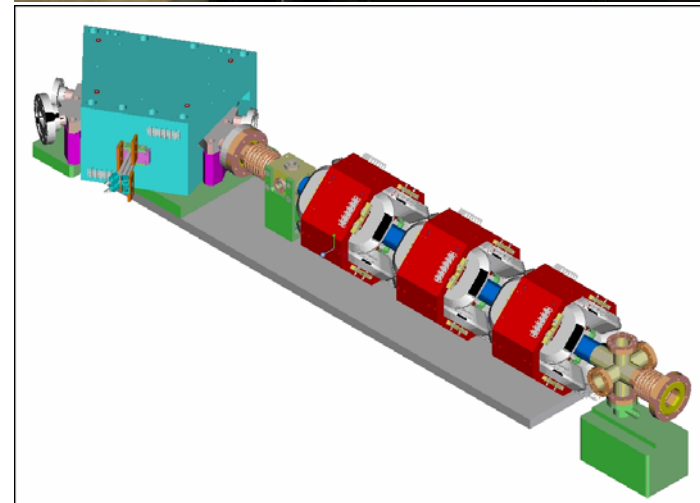
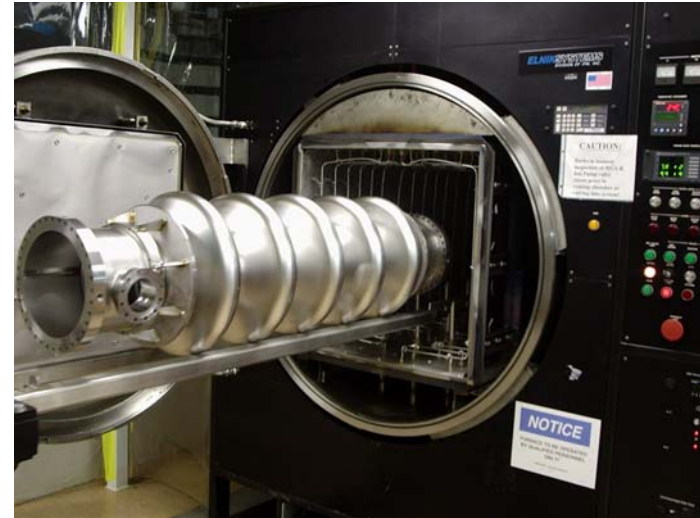


$\langle L \rangle (\text{w/cooling}) / \langle L \rangle (\text{without}) = 5,$   
during 10 hour store



# Hardware development

- Photocathodes, including diamond amplified photocathodes
- Superconducting RF gun
- Energy Recovery Linac (ERL) cavity
- New optical elements (merger)
- Full ERL demonstration



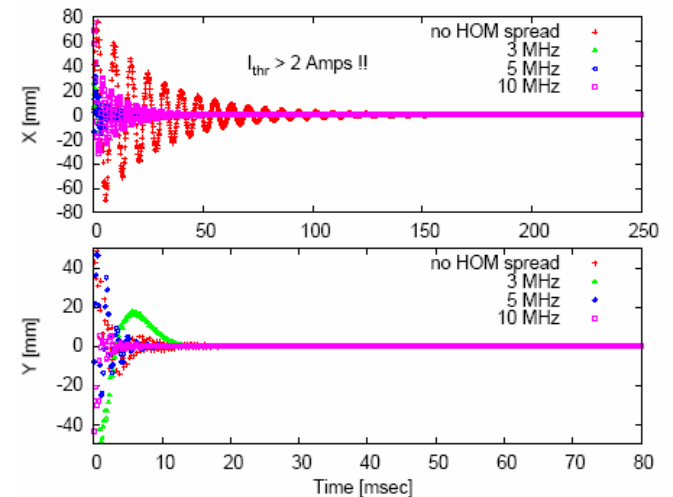
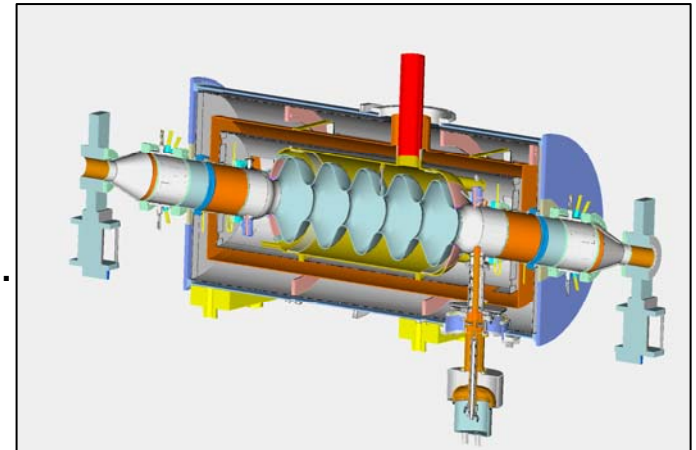
# Ampere SRF ERL cavity



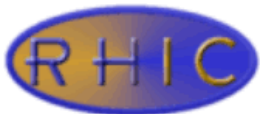
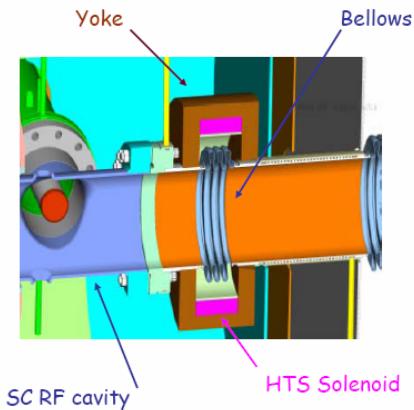
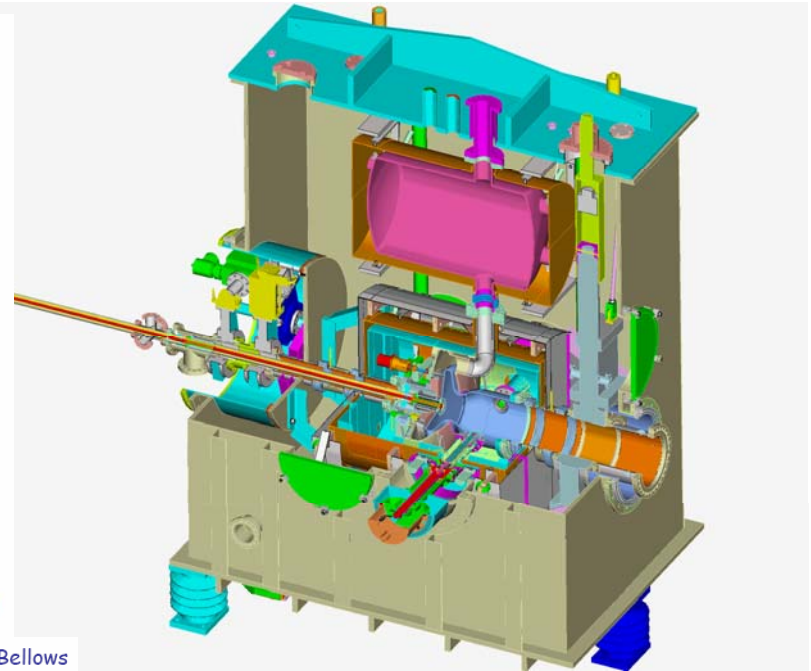
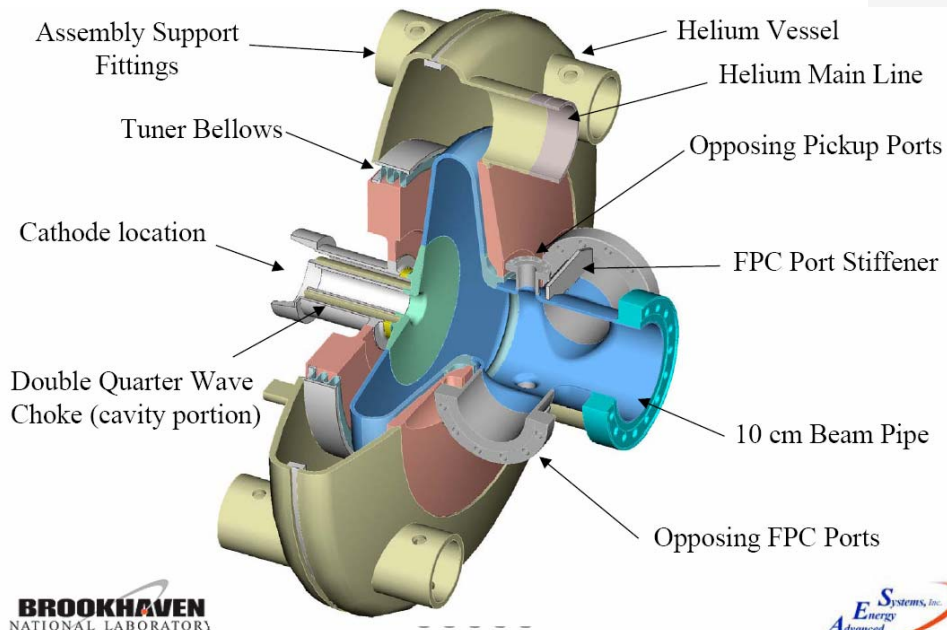
“Single mode”:  
All HOMs damped.  
  
Multi ampere rating.

*Systems, Inc.*  
**Energy**  
*Advanced*

*Jefferson Lab*

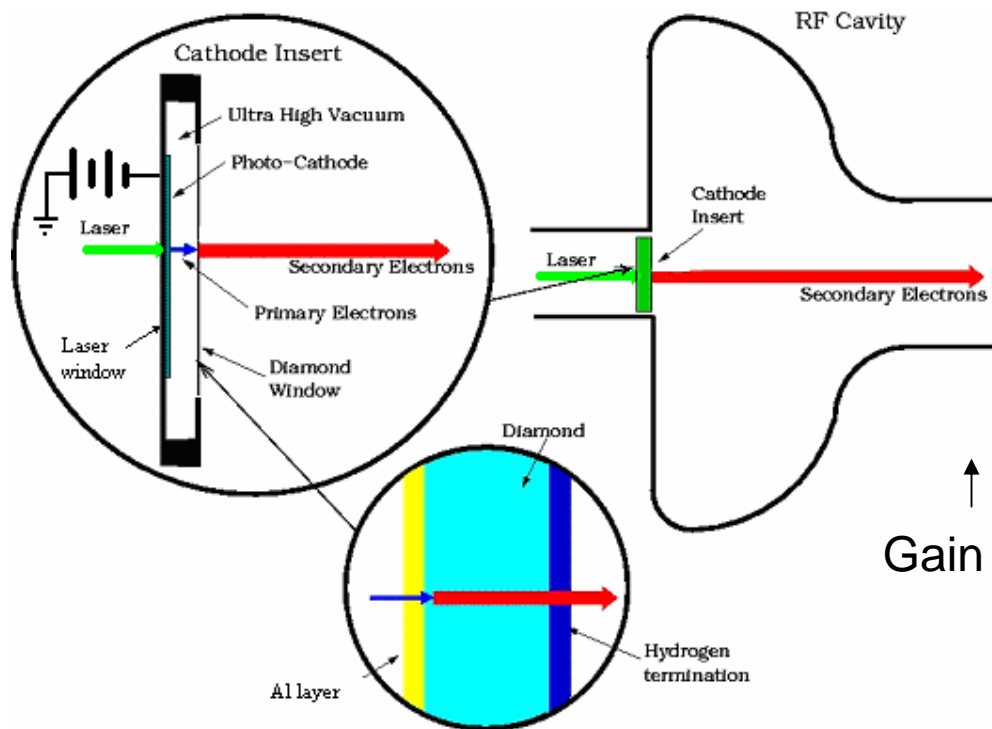


# Ampere superconducting RF gun

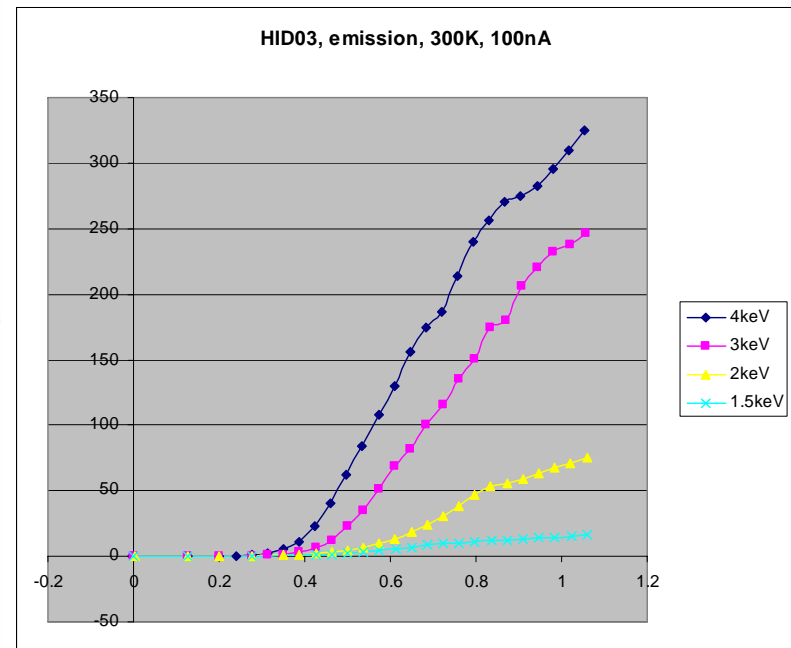


# Diamond amplified photocathode

Ultra-high quantum efficiency photocathode system  
with long life and low thermal emittance

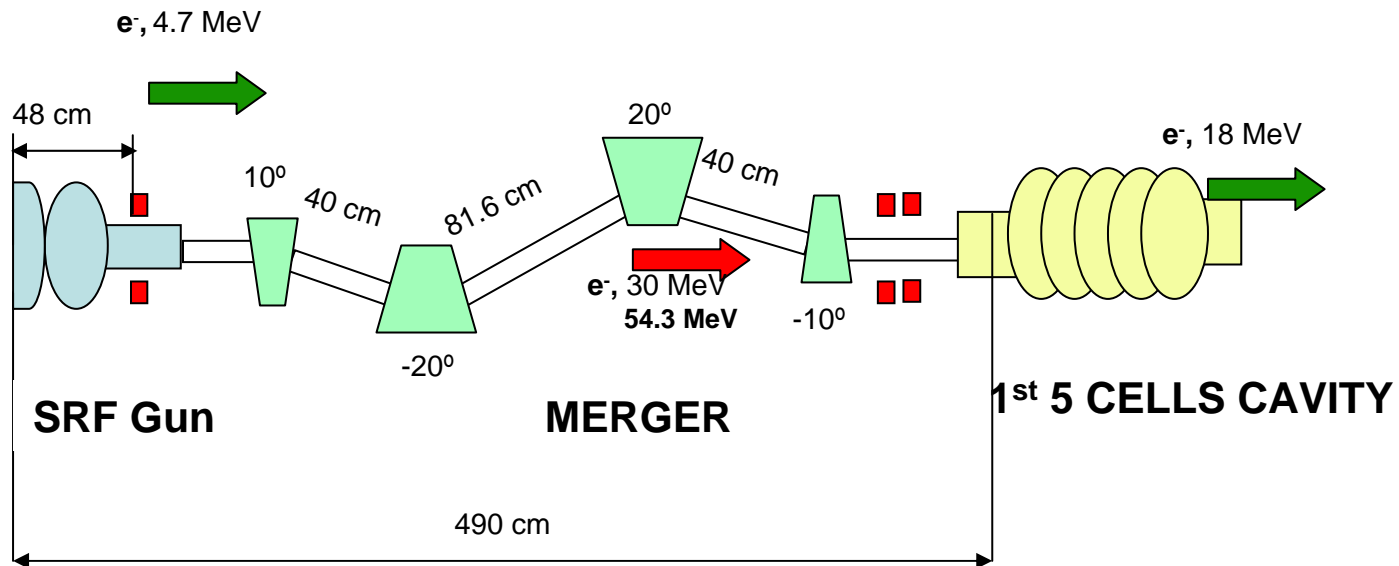


Measurement of amplification



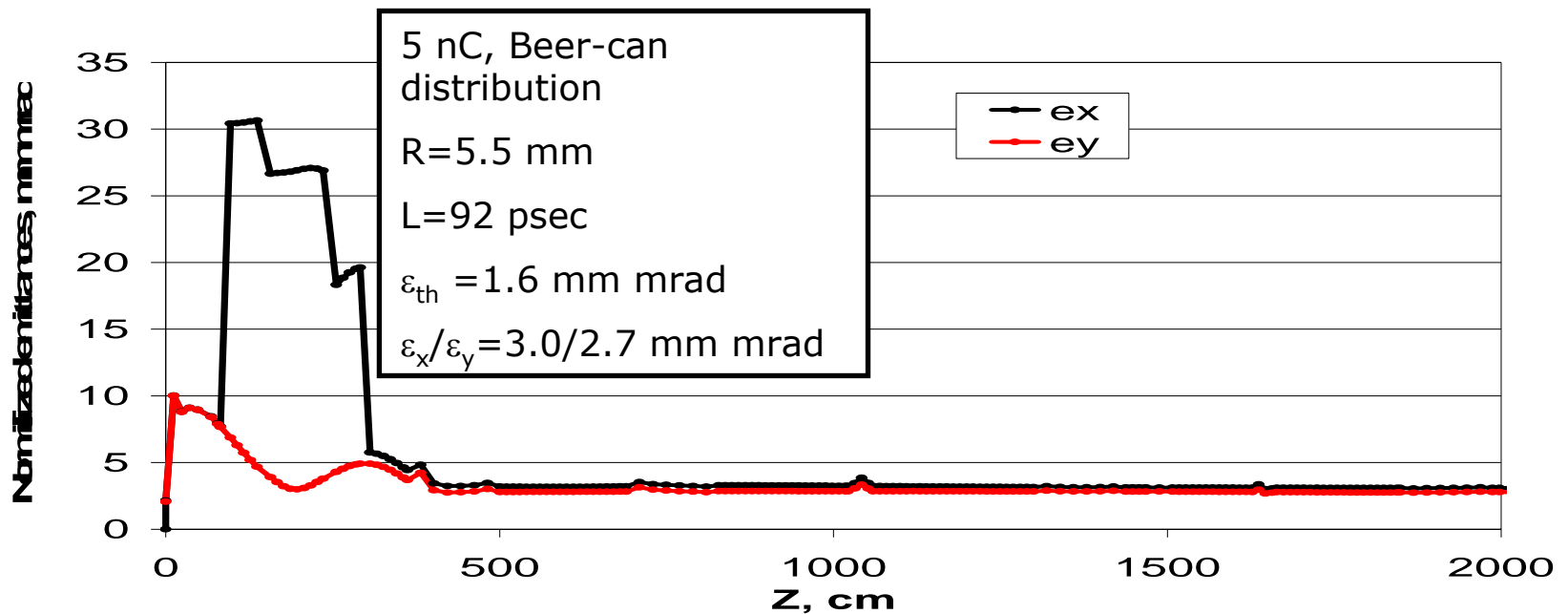
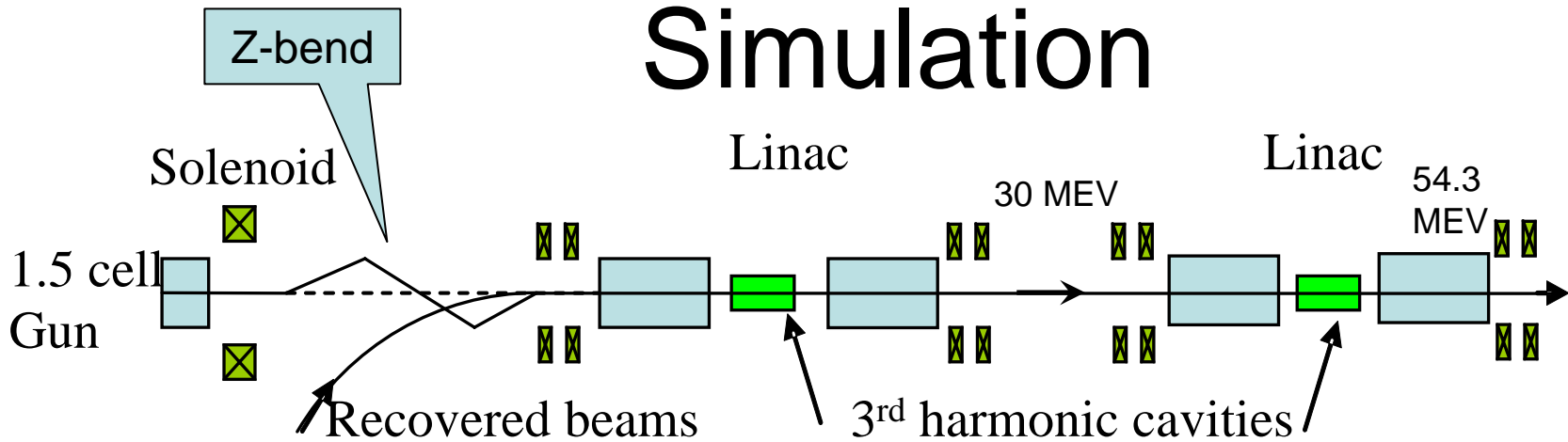
Field in diamond (MV/m) →

# Low-emittance ERL injection

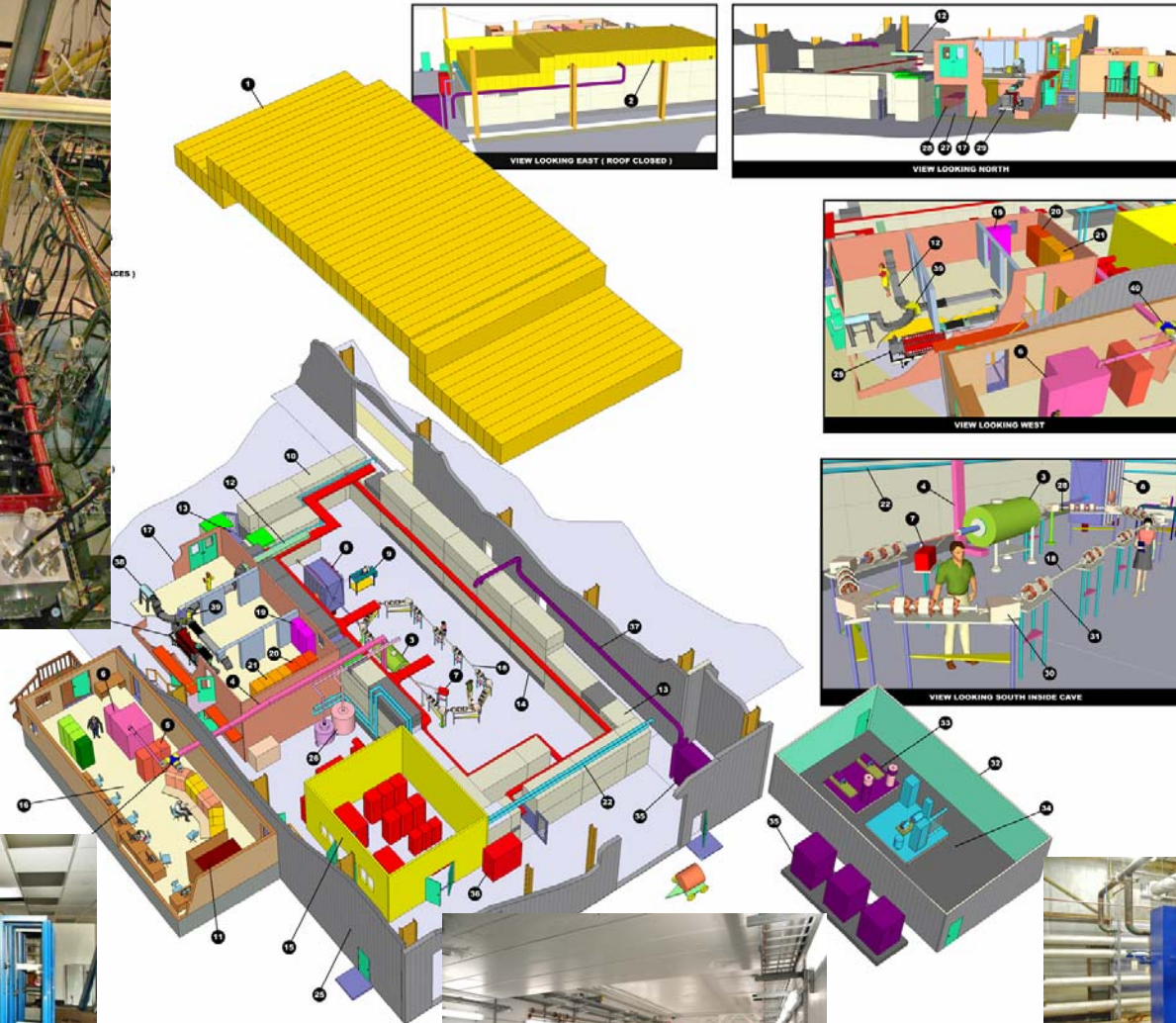


This symmetric beam merging optics solves a long-standing issue of space-charge induced emittance growth in the dispersive plane.

# Simulation



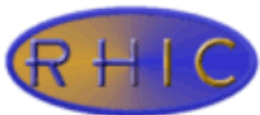
# R&D ERL: To be completed 2008



**BROOKHAVEN**  
NATIONAL LABORATORY

# Status of the R&D

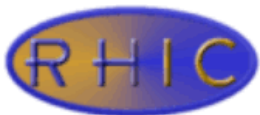
- A lot of information at the electron cooling group web site <http://www.bnl.gov/cad/ecooling/>
- An aggressive R&D program is in place (much more detail in list of accomplishments below)
  - Beam dynamics start-to-end, code verification
  - Cooling theory, simulation and benchmarking
  - Hardware development
    - Photocathode
    - SRF gun
    - ERL cryomodule
    - Demo ERL



# Various other reviews

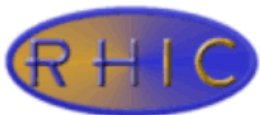
- R&D towards electron cooling started 2000
- October 2004 MAC:
  - “A RHIC luminosity upgrade program has been developed which is based on high energy bunched beam electron cooling. This novel technique which presents a considerable challenge in accelerator physics and in accelerator technology is addressed by an aggressive R&D program.”
- January 2006 MAC:
  - Support of the decision to go to non-magnetized cooling.
- May 2006 Collaboration Workshop on eCooling of RHIC
  - Study of critical physics issues of the non-magnetized cooling of RHIC and the generation of the high-brightness electron beam.

[www.bnl.gov/cad/ecooling/Meetings/May\\_24\\_2006/WorkshopMay06.asp](http://www.bnl.gov/cad/ecooling/Meetings/May_24_2006/WorkshopMay06.asp)



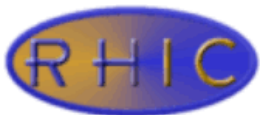
# Accomplishments in past year

- Much of the design had to be changed due to the decision to go for non-magnetized cooling.
- The accomplishments over last year contain too much material to go over in detail.
- Accomplishments grouped by subject in the following:



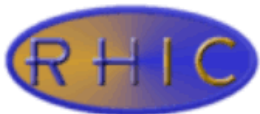
# Beam dynamics

- **Developed and simulated a new concept of achromatic merging compatible with emittance compensation scheme of low-energy high-charge electron beams for energy recovery linacs. Compared to various types of existing and proposed mergers.**
  - **D. Kayran, V. N. Litvinenko. Novel Method of Emittance Preservation in ERL Merging System in Presence of Strong Space Charge Forces. // Proceedings of PAC05, May 16-20, 2005, Knoxville, TN, USA. p. 2512-2514.**
  - ***Dmitry Kayran, Vladimir N. Litvinenko (BNL, Upton, Long Island, New York). A Method of Emittance Preservation in ERL Merging System. // Proceedings of FEL05, August 21-26, 2005, Stanford, CA, USA. p. 644-647.***
  - ***Vladimir N. Litvinenko, Ryoichi Hajima, Dmitry Kayran. Merger design for ERLs. Nuclear Instruments and Methods in Physics Research A 557 (2006), pp. 165 - 175.***
- **Developed magnetic system for ERL with zero transverse dispersion outside and low beta-functions inside 180 degrees arcs. This system has variable longitudinal dispersion and tune shift. Start-to-end PARMELA simulation of beam dynamics in present space charge effect in the ERL for different mode of operation included space charge effects: 1)  $Q=1.4$  nC,  $I=0.5$  A and 2)  $Q=10$  nC,  $I=0.2$** 
  - ***D. Kayran, I. Ben-Zvi, R. Calaga, X.Y. Chang, J. Kewisch, V. N. Litvinenko. Optics for High Brightness and High Current ERL Project at BNL. // Proceedings of PAC05, May 16-20, 2005, Knoxville, TN, USA. p. 1775-1777.***
  - ***S.L. Smith, B.D. Muratori, H.L. Owen, G.H. Hoffstaetter, V.N. Litvinenko, I. Ben-Zvi, M. Bai, J. Beebe-Wang, M. Blaskiewicz, R. Calaga, W. Fischer, X.Y. Chang, D. Kayran, J. Kewisch, W.W. MacKay, C. Montag, B. Parker, V. Ptitsyn, T. Roser, A. Ruggiero, T. Satogata, B. Surrow, S. Tepikian, D. Trbojevic, V. Yakimenko, S.Y. Zhang, Ph. Piot. Optic issues in ongoing ERL projects Nuclear Instruments and Methods in Physics Research A 557 (2006) 145–164***



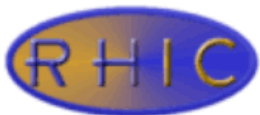
# Beam dynamics

- **A simple ejection system including special shaped dipole and long solenoid with large energy acceptance  $\pm 50\%$  was developed and numerically tested. This ejection system is extremely useful for high power free electron lasers (FELs) based on ERL.**
- **The beam dynamic for different configurations of 0.5 cell super conducting gun for injector helped to finalized design of the gun shape and location of the cathode.**
  - R. Calaga, I. Ben-Zvi, M. Blaskiewicz, X. Chang, D. Kayran and V. Litvinenko. High current superconducting gun at 703.75 MHz Physica C: Superconductivity, Volume 441, Issues 1-2, (2006), 159-179
- **The beam dynamic of two passes high charge per bunch ERL for RHIC electron cooling facility shows required parameters. More studies: non-linear effects from magnets, CSR effects, space charge effects in cooling section and other have to done.**
  - Talk at Collaboration Workshop on RHIC electron cooling and high-brightness electron beams, May 24-26, 2006, Brookhaven National Laboratory.
- **Beam dynamics study of compact superconducting guns and booster linac including the chromaticity effect on emittance compensation**
  - X. Chang, et al., Emittance compensation of compact superconducting guns and booster linac, Phys. Rev. ST Accel. Beams, 9, 044201 (2006).
  - Jorg Kewisch, et. al., Electron Beam Generation and Transport for the RHIC Electron Cooler, Proceedings of PAC05, Knoxville, TN, May 16-20, 2005
- **The study and design of the RHIC e-cooling electron beam injector.**
  - I. Ben-Zvi, et al., Electron Cooling of RHIC, Proceedings of PAC05, Knoxville, TN, May 16-20, 2005
  - J. Kewisch, et al., Electron Beam Generation and Transport for the RHIC Electron Cooler, Proceedings of PAC05, Knoxville, TN, May 16-20, 2005
  - R. Calaga, et al. Ampere class linacs: Status report on the BNL cryomodule, Nuclear Instruments and Methods in Physics Research A 557 (2006) 243–249
  - J. Kewisch, Optimization of gun parameters Collaboration Workshop on RHIC electron cooling and high-brightness electron beams, May 24-26, 2006



# Beam dynamics

- **The study and design of the High Current Energy Recovery Linac (ERL) at BNL**
  - I. Ben-Zvi, et al., Extremely High Current, High-Brightness Energy Recovery Linac, Proceedings of PAC05, Knoxville, TN, May 16-20, 2005
  - D. Kayran, et al., Optics for High Brightness and High Current ERL Project at BNL”, Proceedings of PAC05, Knoxville, TN, May 16-20, 2000
  - V. Litvinenko, et al., High Current Energy Recovery Linac at BNL, Proceedings of PAC05, Knoxville, TN, May 16-20, 2005
  - V. Litvinenko, et al., ERL Based Electron-Ion Collider eRHIC, Proceedings of PAC05, Knoxville, TN, May 16-20, 2005
  - S.L. Smith, et al., Optic issues in ongoing ERL projects, Nuclear Instruments and Methods in Physics Research A 557 (2006) 145–164
  - A. Todd, et al., State-of-the-Art Electron Guns and Injector Designs for Energy Recovery Linacs (ERL), Proceedings of PAC05, Knoxville, TN, May 16-20, 2005
- **Improvement of Theory and Tools for Emittance Compensation**
  - Method for Dead-reckoning the lay-out and focusing strength in an injector
  - Optimizing Code using the Condor method

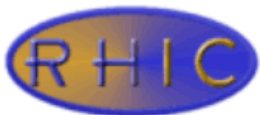


# Beam dynamics

- **Completed design of the Cooler Optics for Magnetized Cooling**
  - The required emittance was achieved using elliptical beam distribution on the cathode: Normalized emittance: 50 mm mrad, Bunch length 5 cm rms, Energy spread  $1 \times 10^{-4}$
  - Using a beer-can distribution a normalized emittance it was not possible to get better than 60 mm mrad.
- **Code Verification**
  - All magnetized beam dynamics calculations were done using the PARMELA program. For the magnetized optics agreement with the Impact-T program was established. Verification for the non-magnetized optics is in progress.
- **Study of electron bunch shapes for non-magnetized Cooling.**
  - The achieved emittance at the end of the linac is 1.2 mm mrad using a elliptical beam distribution. The Bunch length is 1.6 cm rms, the energy spread is  $2 \times 10^{-4}$ .
  - Using a **beer-can** distribution a normalized emittance of 2.5 mm mrad

## Invited talks in the past year

- ERL2005 - V.N. Litvinenko, D. Kayran . Optimum merger for an ERL. ERL 2005, March 19 - 23, Newport News, VA, USA.
- Dmitry Kayran, Xiangyun Chang. Electron beam transport and performance in ERL for RHIC electron cooling. Collaboration Workshop on RHIC electron cooling and high-brightness electron beams, May 24-26, 2006, Brookhaven National Laboratory
- X. Chang, Performance of electron cooler gun, Collaboration Workshop on RHIC electron cooling and high-brightness electron beams, May 24-26, 2006, Brookhaven National Laboratory



# Cooling simulations / benchmarking

**Analysis of experimental data on magnetized cooling,**

(A.V. Fedotov et al., Phys. Rev. E 73, 066503, June 2006)

**Numerical studies of the magnetized friction force,**

(A.V. Fedotov et al., Phys. Rev. ST Accel Beams, V. 9, 074401, July 2006)

**Numerical study of the non-magnetized friction force: benchmarking between VORPAL, BETACOOOL and theory.**

**Experimental studies of the non-magnetized friction force at FNAL Recycler and comparison with BETACOOOL simulations,**

(A.V. Fedotov et al., RHIC cooling Workshop, BNL, May 2006).

**Analysis of experimental data of IBS measurements in RHIC with Cu ions and comparison with theory,**

(A.V. Fedotov et al., in Proceed. of 39th ICFA workshop HB2006, KEK, Tsukuba, Japan, 2006)

**Comprehensive studies of cooling dynamics for RHIC based on the non-magnetized approach,**

(A.V. Fedotov et al., RHIC cooling Workshop, BNL, May 2006)

**Study of the friction force in the presence of undulator field using VORPAL code,**

(D. Bruhwiler et al., RHIC cooling Workshop, BNL, May 2006).

**Study of the effects of magnetic field errors in undulator using VORPAL,**

(G. Bell et al., RHIC cooling Workshop, BNL, May 2006)

**Development of new algorithms in BETACOOOL to simulate experimental data from FNAL cooler,**

(A. Sidarin, A. Smirnov et al.)

**Development of new algorithms in BETACOOOL to simulate IBS for distribution under cooling.**

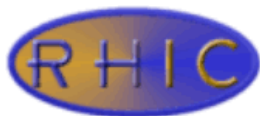
**Implementation of Stochastic and Optical stochastic cooling models in BETACOOOL.**

**Development of fast numerical algorithms to simulate non-magnetized cooling force in BETACOOOL.**

**Development of algorithms to use realistic electron beam distribution from another code for cooling studies within the BETACOOOL.**

**Development of alternative description of cooling based on the IBS formalism,**

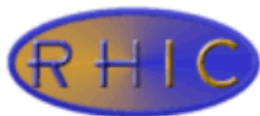
(G. Parzen)



# Cooling simulations / benchmarking

## Invited talks

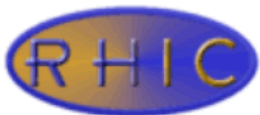
- A. Fedotov, Detailed study of electron cooling friction force, (COOL05, Galena, IL, September 2005)
- A. Fedotov, Electron cooling in RHIC at low energies (Workshop on QCD critical point in RHIC, BNL, March 2006)
- A. Fedotov, Analysis of the magnetized friction force (39th ICFA Advanced Beam Dynamics Workshop HB2006, Tsukuba, Japan, May 2006).
- A. Fedotov, Electron cooling of RHIC, (RHIC electron cooling Workshop, BNL, May 2006).



# Stability

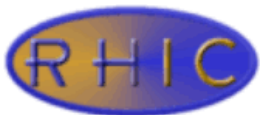
- 1. The dipole instability threshold has been calculated under Parkhomchuk's Model for both magnetized and non-magnetized scheme.
- 2. A dipole coherent damping effects has been verified under the designed electron cooler parameters and the damping rate has been calculated.
- 3. Ion clouds effects within cooling section has been studied and an upper limit of neutralization factor has been derived for varies solenoid field strength.
- 4. The quadruple instability due to the presence of electron beam has been studied both with and without a solenoid in the cooling section. The results show instabilities for a cooling section with solenoid and coherent damping for the current electron cooler design without solenoid.

**Invited talk: Study of stability thresholds due to coherent electron/ion interaction for the non-magnetized approach of RHIC cooling, (G. Wang, RHIC cooling Workshop, BNL, May 2006)**



# Diagnostics

- Diagnostics portion of ERL vacuum envelope design completed
- HOM probes for 5-cell ERL cavity in-house
- Button BPM design completed, ready for procurement
- FPGA-based Diagnostics data acquisition motherboard running in VME with LabVIEW interface
- Preliminary design of broadband (20GHz) 'bi-conal BPM' for cooling section underway, in collaboration with CERN
- Preliminary design of velocity matching diagnostics for electron cooling completed
- Conceptual design of cooling section button BPM electronics completed
- Method of absolute calibration of Schottky transverse emittance measurement developed
- Utilization of beam transfer function measurements for cooling diagnostics under investigation



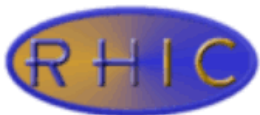
# Diagnostics

- Publications

- P. Cameron, Beam-based Alignment in the RHIC eCooling Solenoids, PAC 2005, Knoxville
- P. Cameron, Beam Diagnostics for the RHIC Electron Cooling Project, DIPAC 2005, Lyon.
- P. Cameron, Differential Current Measurement in the BNL ERL Test Facility, C-A/AP/203, August 2005

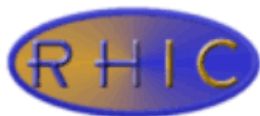
- Workshops, Reviews, Presentations...

- P. Cameron, RHIC Electron Cooling Diagnostics, Collaboration Workshop on RHIC electron cooling and high-brightness electron beams, May 2006, BNL



# Photocathode R&D

- **Multi alkali photocathodes**
  - New deposition system operational-first evaporation underway
  - Collaboration with AES for deposition/transport system for the ERL project
  - Theoretical simulation of photoemission from multi alkali cathode started
- **Diamond secondary electron emission photocathode**
  - Gain ~50 measured in emission mode from a number of diamond samples
  - Gain > 300 measured in emission mode from detector grade diamond sample
  - A number of metal-diamond interfaces have been tested
  - Pulsed electron gun purchased, installed and tested
  - Study of time evolution of SEE is underway
  - Number of samples characterized using Raman, Fluorescence and FTIR spectroscopy and x ray diffraction
  - RF penetration of a thin metallic film was measured
  - Diamond – Nb braze, ceramic-Nb braze successfully completed for capsule formation
  - Theoretical model that includes secondary electron formation, transport through the surface and bulk, scattering, trapping, and emission from the surface is being developed
  - Collaboration established between Tech-X and BNL for modeling diamond secondary electron emission photocathode



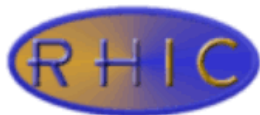
# Photocathode R&D

- **Publications**

- X. Chang, et al, Measurement of the Secondary Emission Yield of a Thin Diamond Window in Transmission Mode, RPPE032, Presented at PAC 05, Knoxville TN, P 2251
- X. Chang, et al, Study of Secondary Emission Enhanced Photoinjector, TPPE042, Proc. Of PAC 05, Knoxville TN P 2711
- A. Burrill, et al, Multi-Alkali Photocathode Development at Brookhaven National Lab for Application in Superconducting Photoinjectors, TPPE041 Proc. Of PAC 05, Knoxville TN, P 2672
- T. Rao, et al, Role of Diamond Secondary Emitters in High Brightness Electron Sources; BNL 74975-2005CP; pres. at 1st Int'l. Industrial Diamond Conf., 20-21 October (2005), Barcelona, Spain
- T. Rao, et al, Photocathodes for the energy recovery linacs; Nuc. Inst. and Meth. in Phys. Res. A557 124 (2006)
- J. Smedley, et al, Superconducting Photocathodes; Proceedings of Workshop on the Physics and Applications of High Brightness Electron Beams, Erice, Sicily, October 9-14, 2005
- Y. Zhao, et al., The Penetrability of a Thin Metallic Film Inside the RF Field, Proceedings of PAC05, Knoxville, TN, May 16-20, 2005

- **Invited talks**

- Diamond Secondary Emitter, I. Ben-Zvi, T. Rao, A. Burrill, X. Chang, J. Grimes, J. Rank, Z. Segalov And J. Smedley, Proceedings of Workshop on the Physics and Applications of High Brightness Electron Beams, Erice, Sicily, October 9-14, 2005
- Final Design Review for Photocathode Preparation Chamber and Cathode Transport System, July 14, 2005, T. Rao, BNL Diamond & Multi-Alkali Status
- Photocathode SBIR Phase II Kickoff Meeting AES, Medford, NY –April 4, 2006, A. Burrill, T. Rao: Review of BNL work to date on CsK2Sb Photocathodes
- C-AD Machine Advisory Committee Meeting, January 23-24, 2006, A. Burrill and T. Rao: Photocathode
- Collaboration meeting on Polarized electron source for eRHIC / ILC, March 29, 2006, T. Rao, Photocathode research
- Collaboration Workshop on RHIC electron cooling and high-brightness electron beams, May 24-26, 2006, Brookhaven National Laboratory, T. Rao: The photocathode scenario and laser requirements

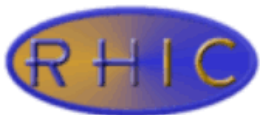


# Cryomodule

- Cryomodule Contract Awarded to AES 07/14/03
- Phase 1 Complete (Design, Material Procurement, Cu Cavity) 09/30/04
- Phase 2 Complete (Cavity& Cryomodule Components Delivered) 04/10/06
- Cavity BCP & He Vessel Welding adaptive tooling complete 01/10/06
- Cavity & Tooling Delivered to JLab 01/31/06
- Deliveries of Cryomodule Components Complete 04/10/06
- CMM & Heat Treating of Cavity Complete at JLab 04/26/06
- Second Shipment of Tooling and Components to JLab 04/28/06
- Start of Cavity's First VTA Testing 06/30/06
- Final Shipment of Tooling and Components to JLab 08/15/06
- Expected start of Cavity String Assembly 09/01/06
- Expected Delivery to BNL of Cavity String 10/27/06
- Expected start of Cryomodule Horizontal Testing 01/26/07

## Recent publications:

- I. Ben-Zvi, et al., Extremely High Current, High-Brightness Energy Recovery Linac, Proceedings PAC'05, Knoxville Tennessee, May 16-20 2005.
- R. Calaga, et al., Ampere class linacs: status report on the BNL cryomodules, Nucl. Instr. and Meth. In Phys. Res. A 557 (2006) 243



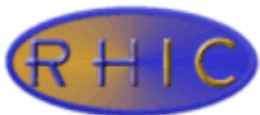
# SRF gun

## 1.3 GHz SRF Photoinjector

- 1.3 GHz SRF injector modified to accommodate a demountable cathode stalk using a quarter wave choke joint assembly
- Modified injector tested in VTA, Q value without cathode insert  $8.5 \times 10^9$  at 2K
- Q value with cathode insert  $\sim 10^{10}$ , multipacting barrier encountered at 2MV/m
- Alternate cathode inserts fabricated and tested, similar performance as original components
- Lead coated cathode stalk tested in SRF injector Q of  $1.6 \times 10^9$
- Multipacting simulations performed on choke joint region of cavity, multipacting region identified as outer cathode stalk region that was not grooved.
- Multiple alternate choke joint geometries simulated to find best possible solution that would not require inserting multipacting suppression grooves in outer choke region
- Top loading cryostat designed to allow for better testing of 1.3 GHz gun at BNL once facility infrastructure is in place

## 703.75 MHz SRF photoinjector

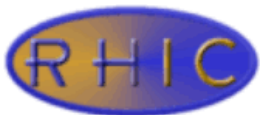
- Physics Design (Shape, emittance, HOM mode, coupling, multipactoring...) finished July 2005
- Final Design Review, December 2005.



# SRF gun

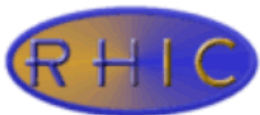
## Related Publications:

- J. Sekutowicz, et al., Nb-Pb Superconducting RF-Gun; Proceedings to EPAC 2006.
- T. Rao, et al., Design, construction and performance of all niobium superconducting radio frequency electron gun; Nucl. Instr. & Metho. In Phys. Res. A 562, 2006
- M. Cole, et al., RF Design and Operating Performance of the BNL/AES 1.3 GHz Single Cell Superconducting RF Photocathode Electron Gun, TPPE061 Presented at PAC 05, Knoxville TN, P 3514
- T. Rao, et al., Photoemission Studies on BNL/AES/JLab all Niobium, Superconducting RF Injector, WPAP038 Presented at PAC 05, Knoxville TN, P 2556
- J. Smedley, et al., Progress on Lead Photocathodes for Superconducting Injectors, WPAP039, Presented at PAC 05, Knoxville TN P 2598
- Y. Zhao, et al., The Penetrability of a Thin Metallic Film Inside the RF Field, WPAT049, Presented at PAC 05, Knoxville TN P 3073
- J. Smedley, et al., Superconducting Photocathodes; Proceedings of Workshop on the Physics and Applications of High Brightness Electron Beams, Erice, Sicily, October 9-14, 2005
- R. Calaga, et al., High Current Superconducting Gun at 703.75 MHz, Proc. 2005 SRF International Workshop, Cornell Univ. July 10-15, 2005
- A. Burrill, et al., BNL superconducting RF guns—technology challenges as ERL sources, Nuclear Instruments and Methods in Physics Research A 557 (2006) 75–79



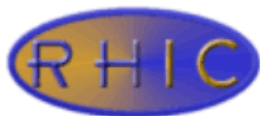
# ERL facility

- Klystron shielding enclosure fabricated & installed.
- Klystron power supply enclosure purchased & installed.
- 4160V Klystron power sub-station and feed installed.
- Pump room building refurbished.
- Tower piping and de-ionized water system completed.
- Counting house refurbished.
- 120/208V electric power distribution completed.
- Blockhouse Access Controls 80% complete.
- Ballast tank purchased and stand fabricated.
- High pressure dewars purchased.
- Helium vacuum pump, vaporizer and warm piping installed.
- Survey controls established.
- 50kW power supply and transmitter installed.



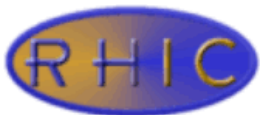
# ERL Magnets

- ERL Loop Quad and Dipole Magnet Bid Package Complete 01/05/06
  - (included all drawings and technical specifications)
- ERL Loop Quad and Dipole Order Awarded 03/10/06
- ERL Loop Dipole Chamber Bid package Complete 06/08/06
  - (included all drawings and technical specifications)
- ERL Loop Quad Chamber Bid package Complete 06/21/06
  - (included all drawings and technical specifications)
- First Article Quad Delivery (projected) 07/25/06
- First Article Dipole Delivery (projected) 08/22/06



# ERL RF

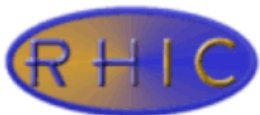
- 1 MW system
  - Klystron
    - Testing
      - Testing of the klystron was successfully completed on May 4, 2006.
      - Using TLDs, radiation was recorded to map levels. This will be useful in determining radiation safety measures.
      - The 1.3 MW rated load manufactured by MEGA was tested, and failed at 500 kW. This was the second power failure, and the unit was returned for a refund.
    - Installation
      - The klystron has been delivered to BNL. The unit was inspected, and bolts loosened in transit were tightened, where required.
      - The tube is being kept at vacuum until use by the continuous pumping with a Dual Vaclon pump controller.
      - Design support has helped in the construction of the steel shielding for the klystron room.
    - High Power Dummy Load
      - Procurement
        - An order was placed June 2, 2006 with CML engineering for a ceramic based dummy load.
        - Final detailed drawings of the unit will be submitted by the vendor before the end of July, 2006. Delivery is scheduled for December 15, 2006.



# ERL RF

## – Klystron Transmitter and HVPS

- Transmitter Status
  - Construction is complete, small problems must be fixed.
- HVPS Status
  - Original construction is complete. Additional metering of the 4160 VAC input to the transmitter is being added to enhance safety.
  - Noise in the regulator circuit has been resolved. A new circuit card assembly is being constructed.
- Schedule for Final Acceptance Testing (FAT) and Shipping
  - August 25, 2006- Submission of pre-FAT data
  - September 11-29, 2006 - FAT
  - October 2-13, 2006 - Disassemble / pack
  - October 13, 2006 - Ship
  - October 20, 2006 - Arrival at BNL



# ERL RF

- LLRF development for 50 kW and 1 MW systems
  - Completed design and fabrication of the RF Upgrade PMC prototype LLRF Digital Controller. Board is undergoing preliminary testing, and initial results have so far been entirely positive. Purpose of board is to test a variety of new digital technologies which will ultimately find use in the LLRF Digital Controller for the ERL. This is an extremely important milestone.
  - Completed conceptual design of the analog PLL LLRF test controller to be used for initial testing of the ERL 5-cell cavity as soon as installation is completed.
  - Have begun modeling efforts aimed at analyzing stability and robustness of the LLRF digital control system. Initial efforts are focused on I&Q control of the ERL 5-cell cavity, and will be extended in steps to include the ERL gun, beam dynamics, etc.
- 50 kW system:
  - Transmitter is installed and being tested every other week;
  - All waveguides from circulator to the ring installed.

